

Relativistic Emission Lines and Ionized Outflow in NGC 4051 Measured with XMM

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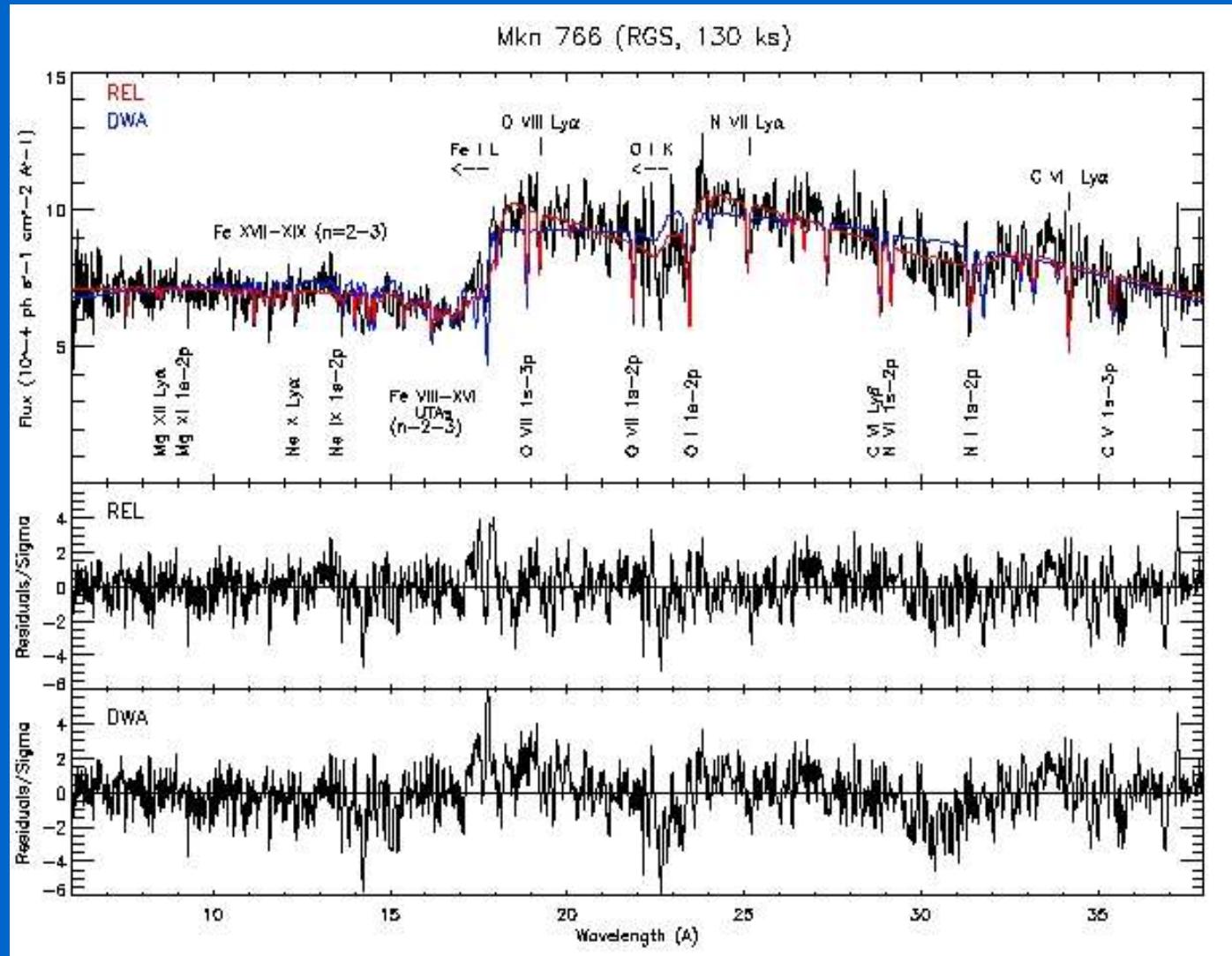
K. O. Mason, M. J. Page, N. J. Salvi MSSL

F. A. Cordova, I. M. McHardy, W.C. Priedhorsky

Overview

- ★ Emission lines from the inner accretion disk:
Mkn 766
NGC 4051
- ★ NGC 4051 outflow: kinematics, ionization.
- ★ NGC 4051 variability, low vs. high-state spectra.

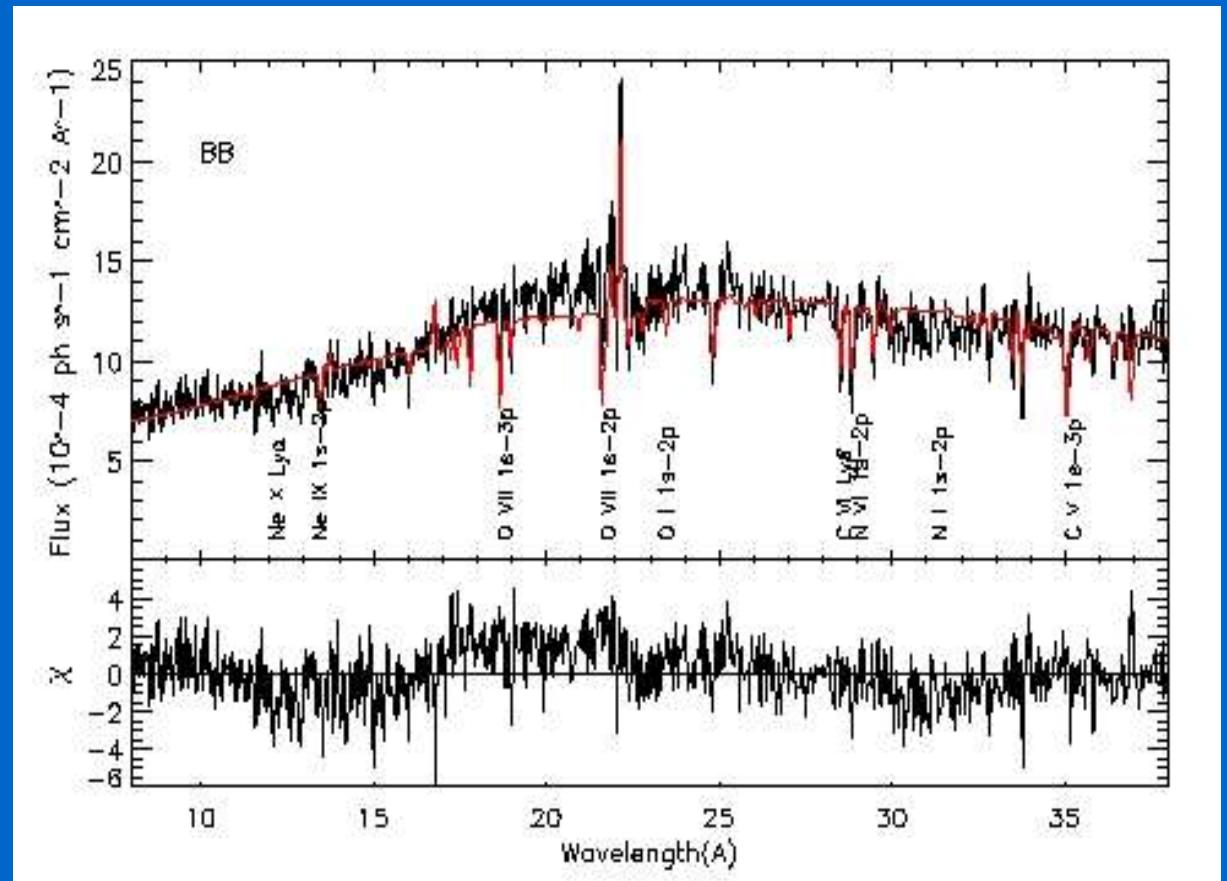
Relativistic Lines in Mkn 766



Mason et al., Sako et al. 2003, Branduardi-Raymont et al., Lee et al. 2001

NGC 4051 Soft X-ray Excess

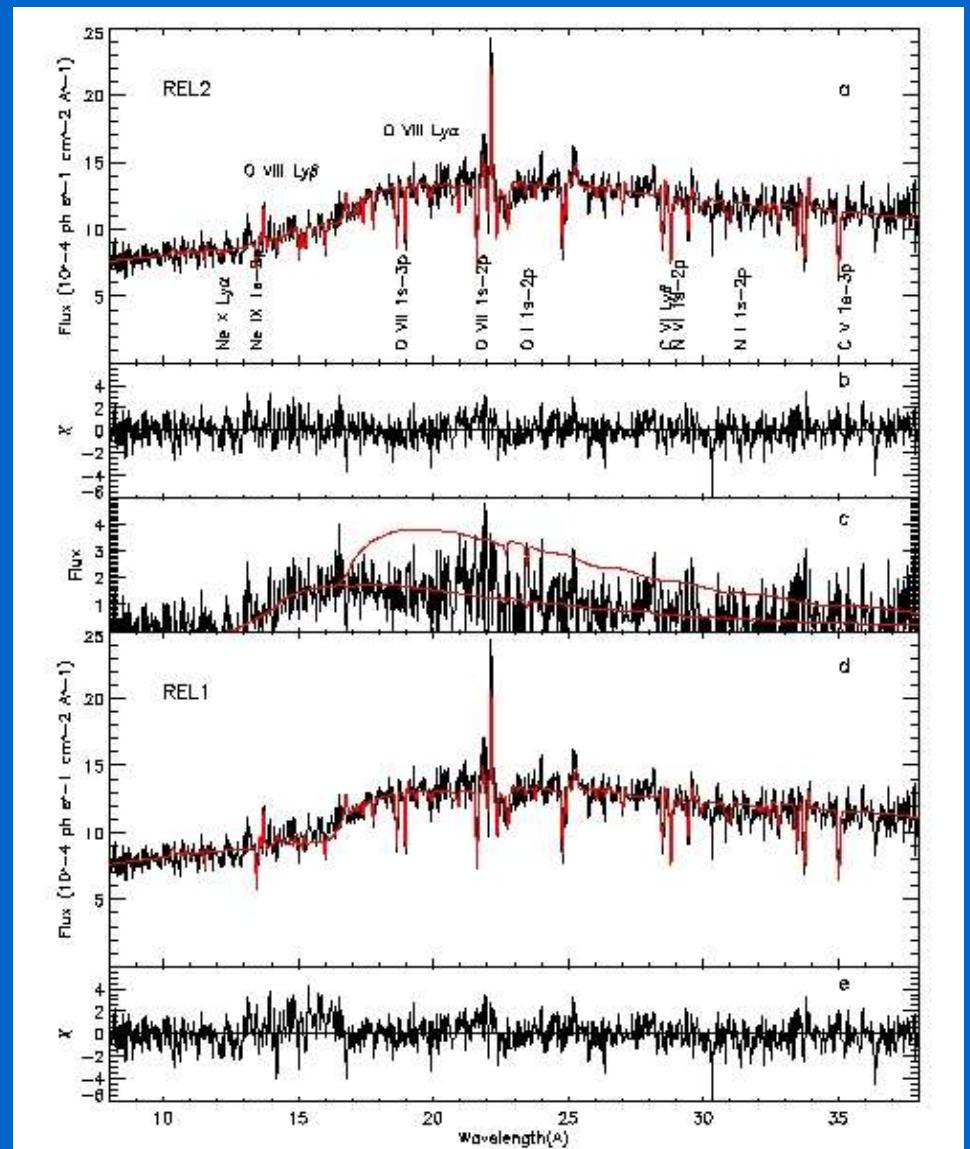
- RGS, 100 ks
- PL: $\Gamma = 2.35$
- BB: $kT = 0.13$ keV
- Fit $\chi^2/\text{DF} = 2.39$ is very poor!
- ★ Broad bump and no obvious PI edges.



Ogle et al. 2003, Collinge et al. 2001, Guanazzi et al. 1998

Relativistic O VIII in NGC 4051

- Rel. line fits
- a: O VIII series
- b: residuals
- c: Ly β + higher order lines
- d: O VIII Ly α only
- e: residuals

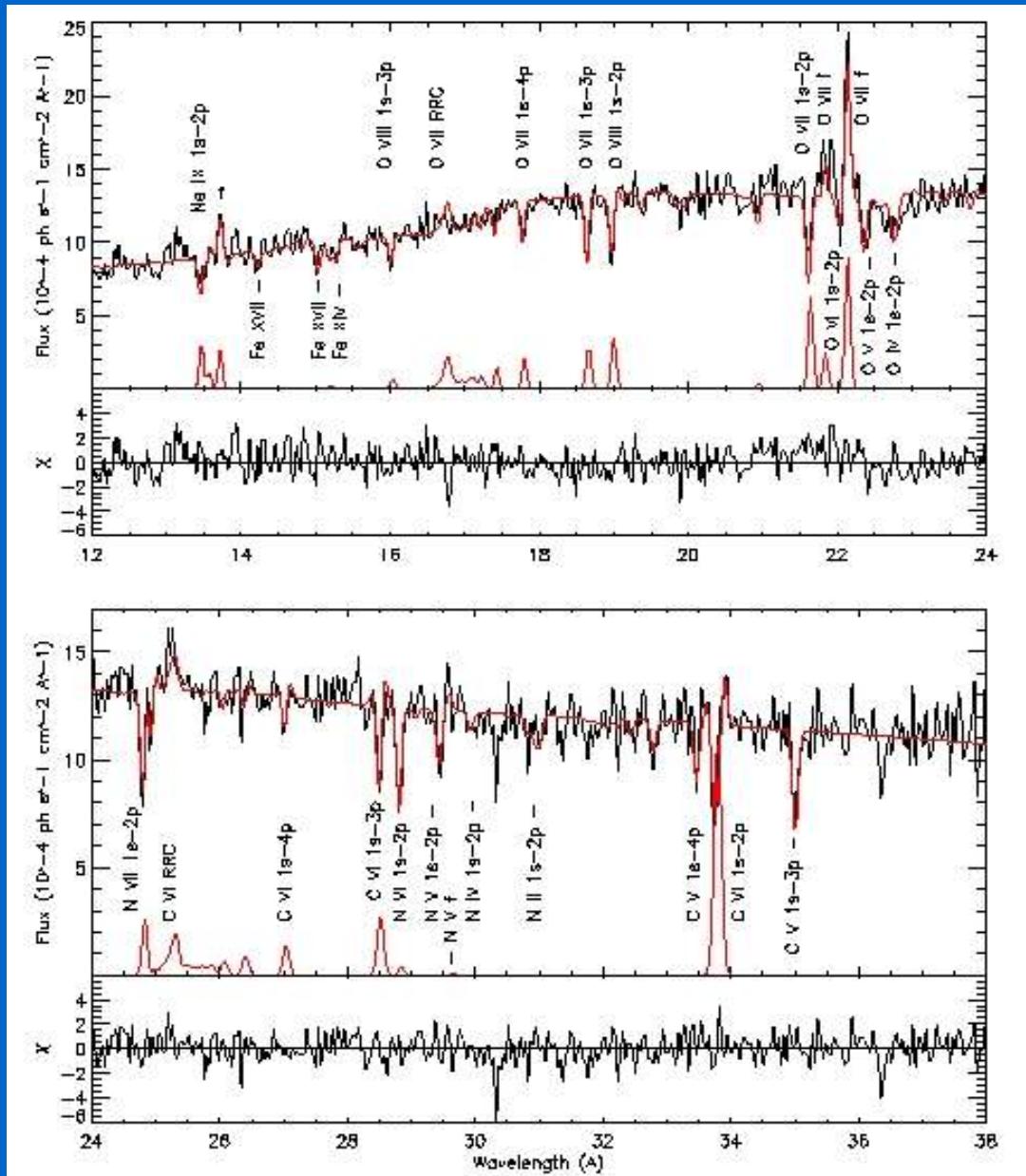


RLR parameters

- Best fits O VIII Laor/series: $\chi^2/\text{DF} = 1.65, 1.38$
- Radii: $R_i = 1.24 R_G$, fixed ($R_G = GM/c^2$)
 $R_o = 400 R_G$, fixed
- Line Emissivity $\sim R^q$ ($q = -5.24 \pm 0.07$)
(Half-light radius = $1.53 R_G$)
- Inclination: $i = 47.1 \pm 0.5$, matches [O III] cone
(Christopoulou et al. 1997)
- $M_{\text{BH}} = 1.5 \times 10^6 M_{\text{sun}}$ ($M_{\text{BH}} \sin i$: Peterson et al. 2000)
- N VII/O VIII < 0.09, C VI, O VIII < 0.14
- Fe XXV: $R_i = 1.56 R_G$, $q = 6.2$, $i = 57 \pm 10^\circ$, $\text{EW} = 70 \text{ eV}$

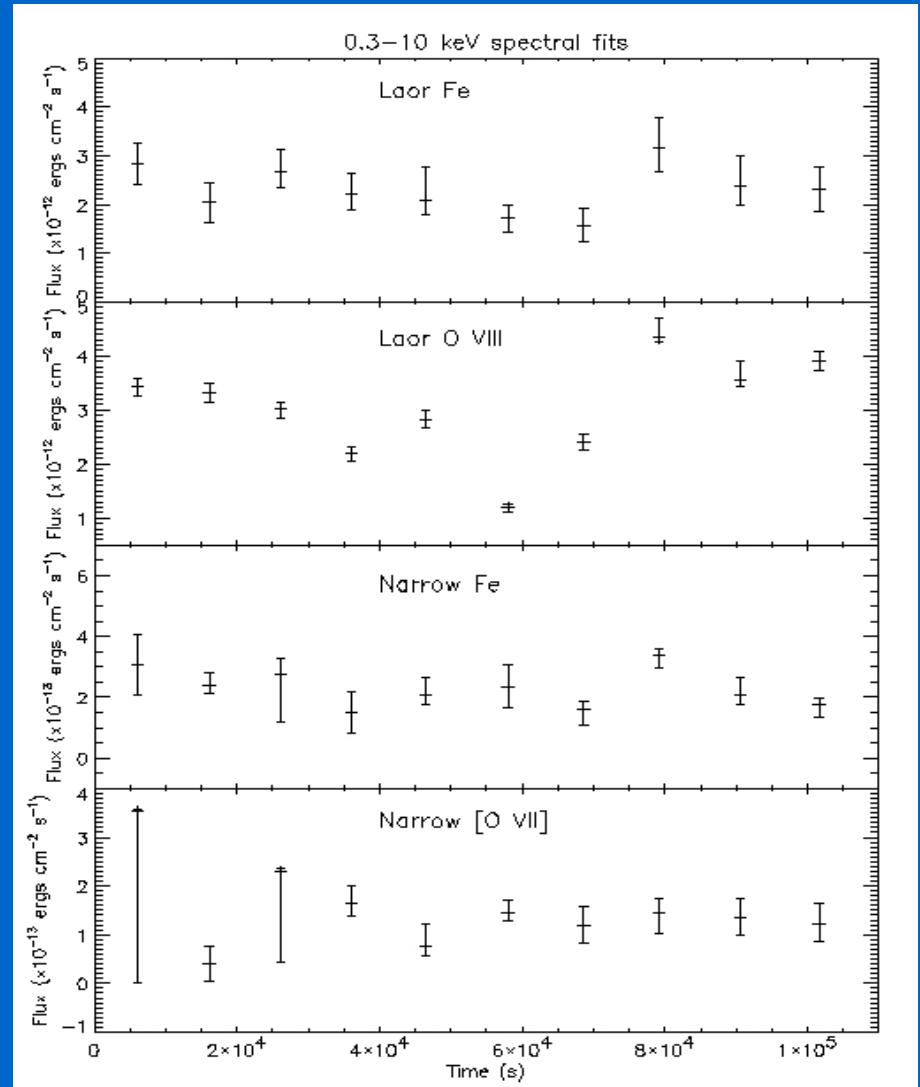
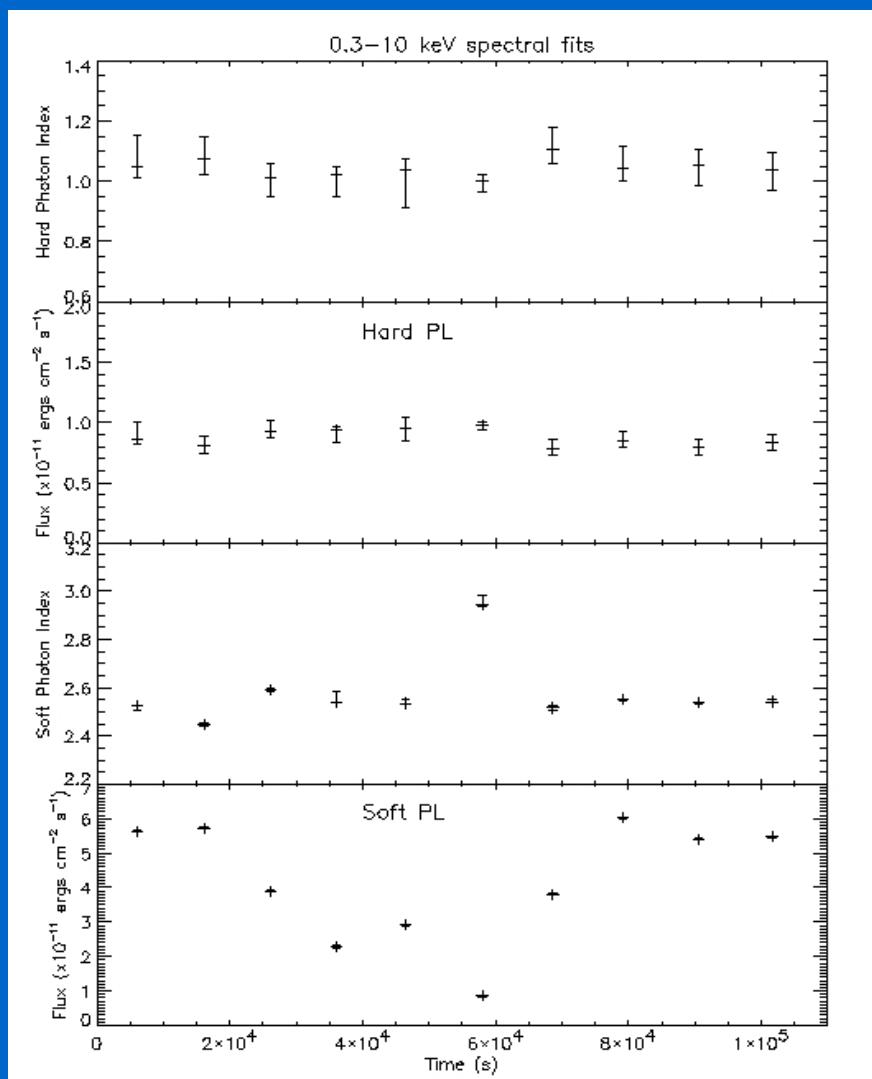
NGC 4051 ionized absorber/emitter

- ★ Absn series from:
K-shell C, N, O, Ne,
inner-shell N, O
L-shell Fe.
- $V_a = -670 \pm 150 \text{ km/s}$,
 $b = 192 \pm 8 \text{ km/s}$
- ★ Re-emission partially fills
absn lines. ($f_c = 77\%$)
- O VII, Ne IX i, f,
- $V_e = -160 \pm 90 \text{ km/s}$
- ★ Broad C VI Ly α , RRC
 $b=700 \text{ kms} \pm 30 \text{ km/s}$



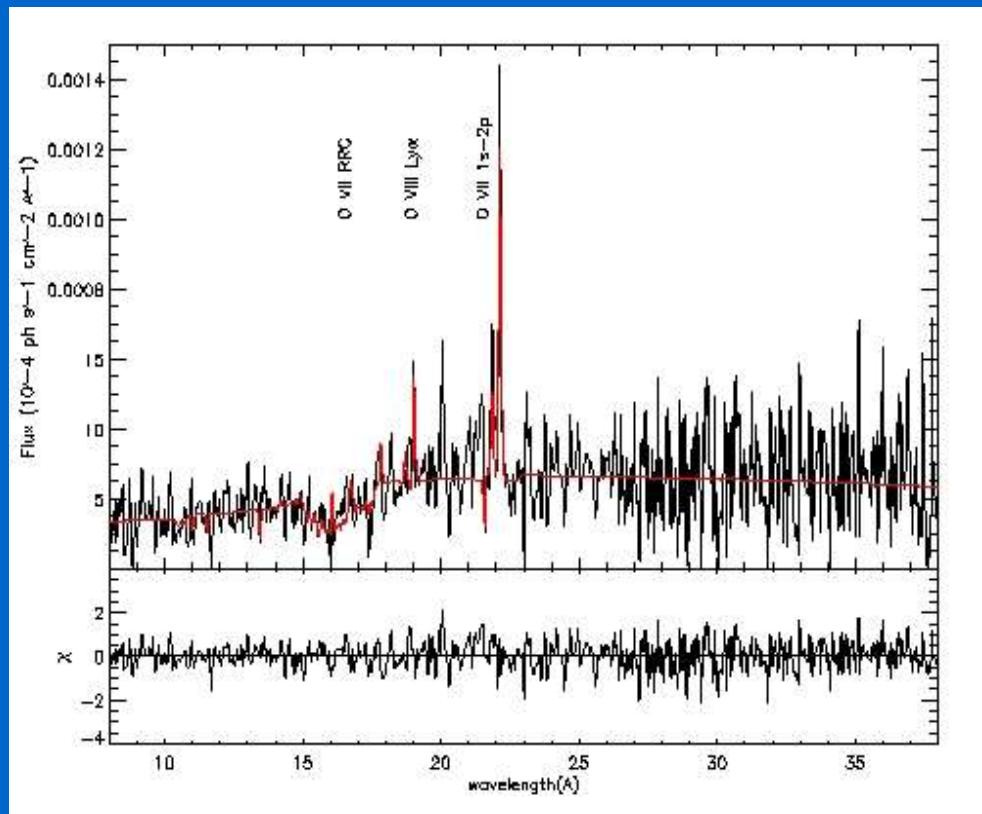
Epic spectral variability

Salvi et al. 2003, same epoch as RGS



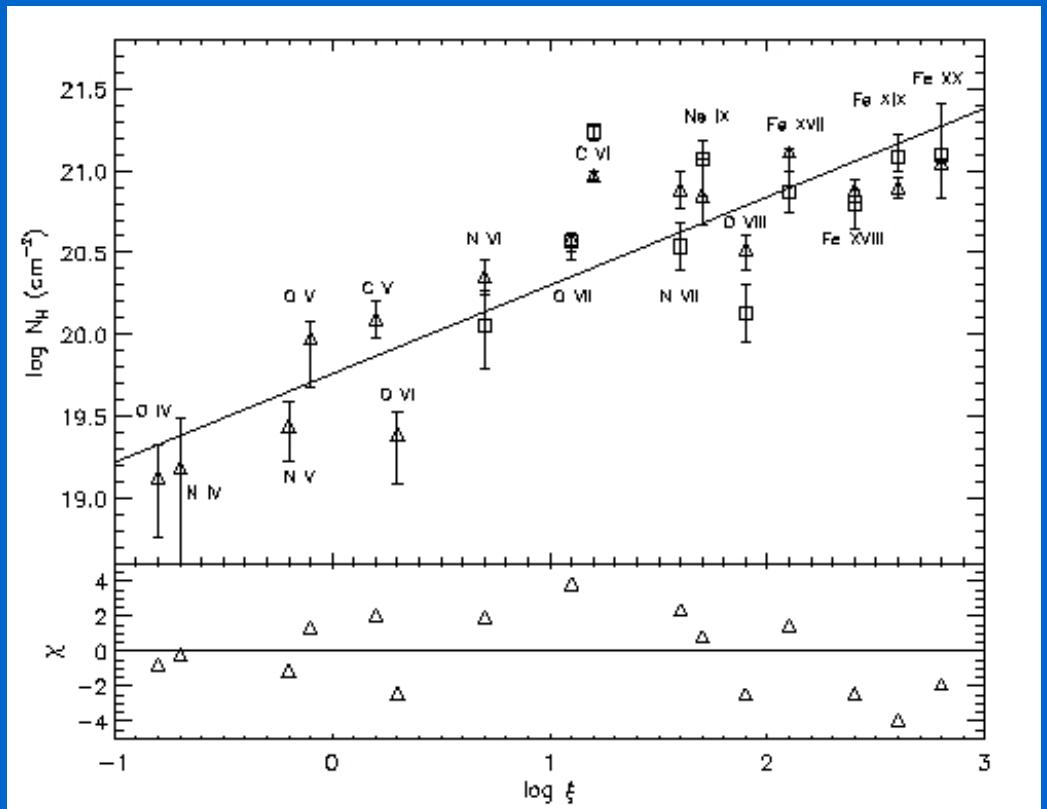
NGC 4051 low-state RGS spectrum

- ★ Rel. O VIII still there!
- High EW O VII, O VIII narrow lines.
- Absorber parameters not well constrained, but consistent with high state.
- Possible UTA



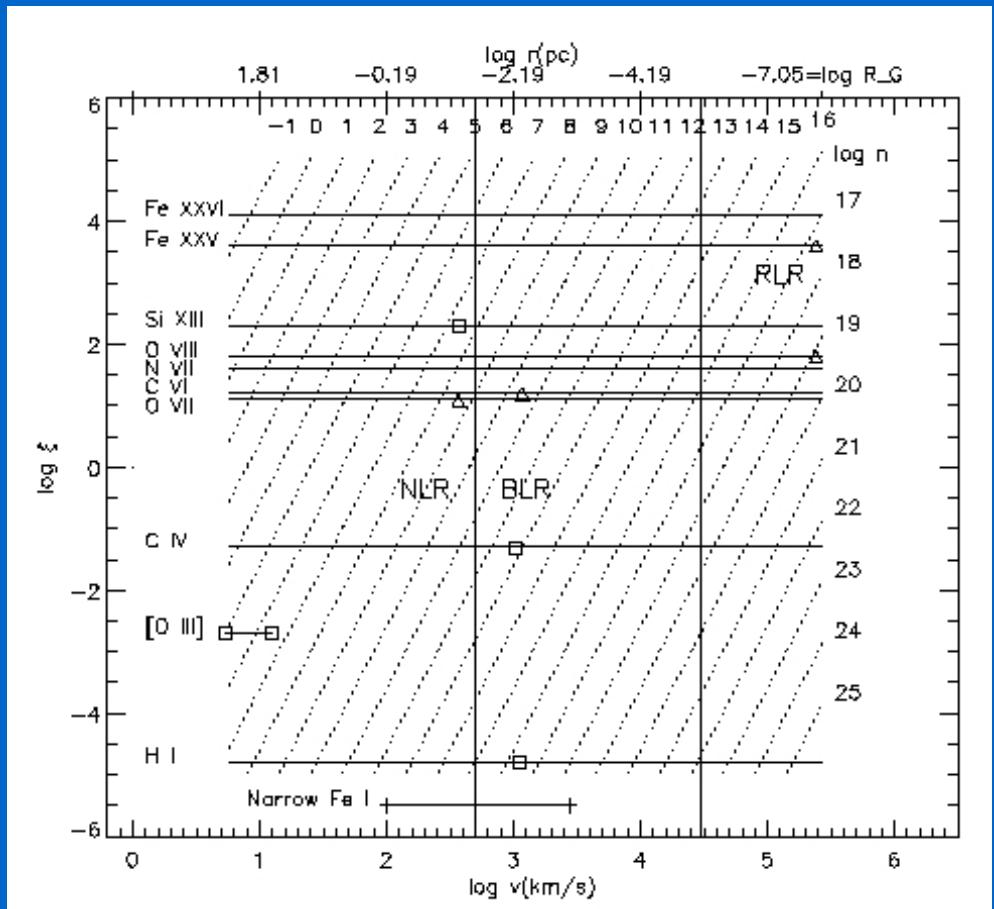
Absorber Ionization Distribution

- ★ Strong trend of increasing column density with ionization parameter $\xi = L/nr^2$.
- Emitter and absorber have similar columns.
- See also: Steenbrugge et al. 2003, NGC 5548



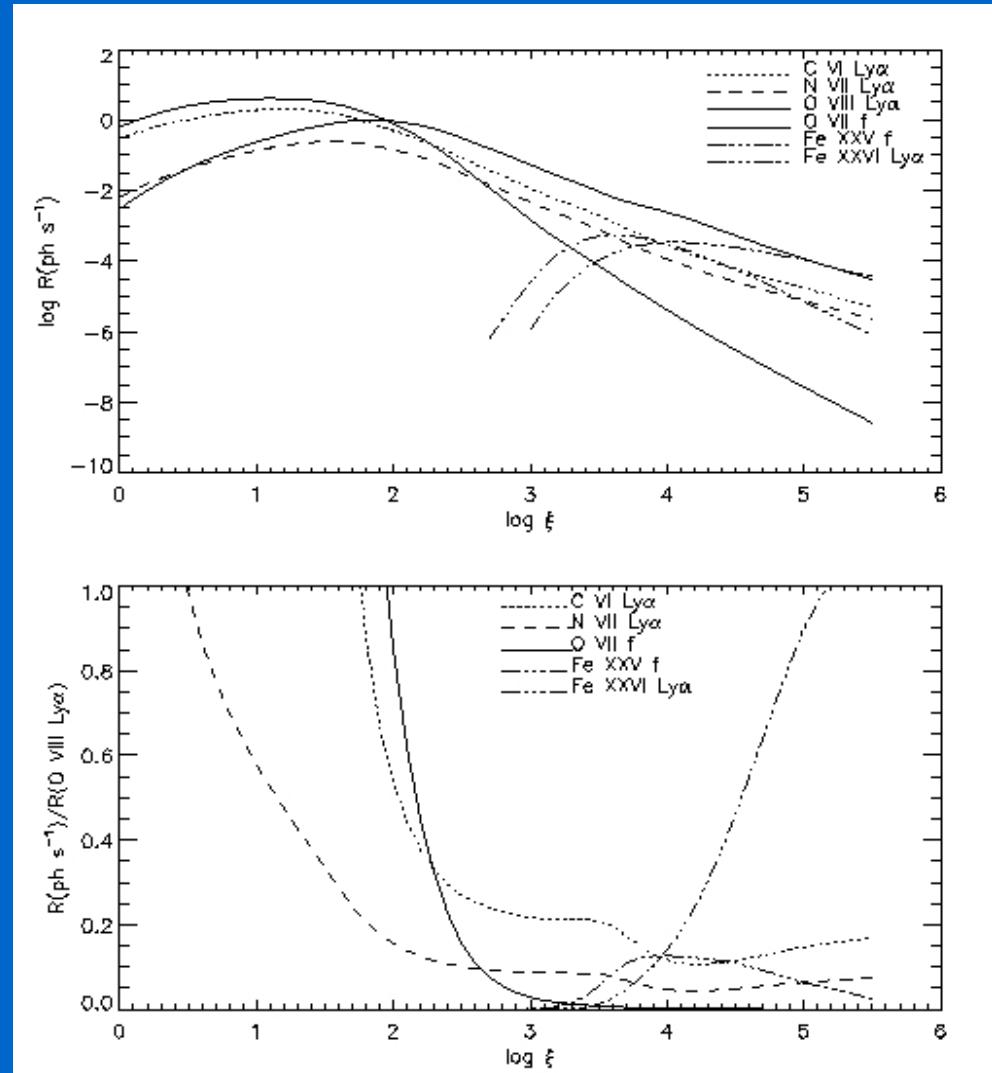
Emission line regions: radial/ionization distribution

- ◆ $M_{BH} = 1.5 \times 10^9 M_{\text{sun}}$,
Keplerian orbits.
- ★ NLR and BLR span
enormous range of
ionization parameter and
density.
- ★ What causes the gap
between RLR and BLR?



RLR Ionization and Abundances

- Strong Fe XXV, no O VII imply high ionization parameter ($\log \xi = 4.0$).
- ★ Strong O VIII but no N VII consistent with solar abundances.
- Bowen resonance? - Sako 2003.



Summary

- Relativistic O VIII Ly α and higher order lines discovered in NGC 4051, respond to soft X-ray flux.
- Emission from photoionized disk at $1.5 R_G$, with solar abundances, (low optical depth)
- Ionized outflow with $\log \xi = -1$ to 3, most mass in high ionization states.
- Broad C VI emission from BLR, large range in ionization parameter.
- *Relativistic soft X-ray lines are real, and diagnostic of accretion disk geometry and state.*